PAPER PRODUCTS

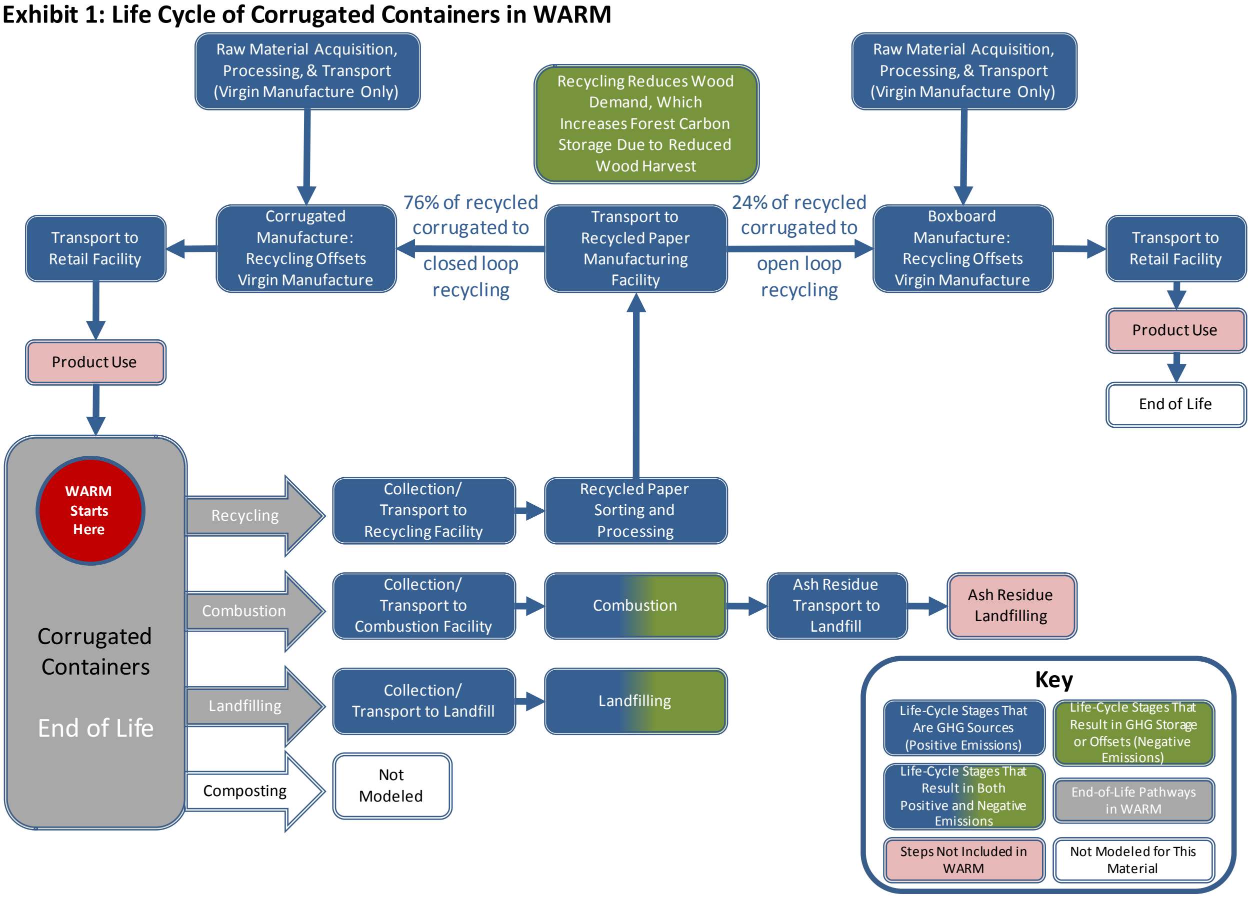
1. INTRODUCTION TO WARM AND PAPER PRODUCTS

This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for paper products beginning at the point of waste generation. The WARM GHG emission factors are used to compare the net emissions associated with paper products in the following four waste management alternatives: source reduction, recycling, landfilling, and combustion. For background information on the general purpose and function of WARM emission factors, see the Introduction & Overview chapter. For more information on Source Reduction, Recycling, Combustion, and Landfilling, see the chapters devoted to those processes.

The paper products addressed in WARM comprise corrugated containers, magazines/third-class mail, newspaper, office paper, phone books, textbooks and three definitions of mixed paper.

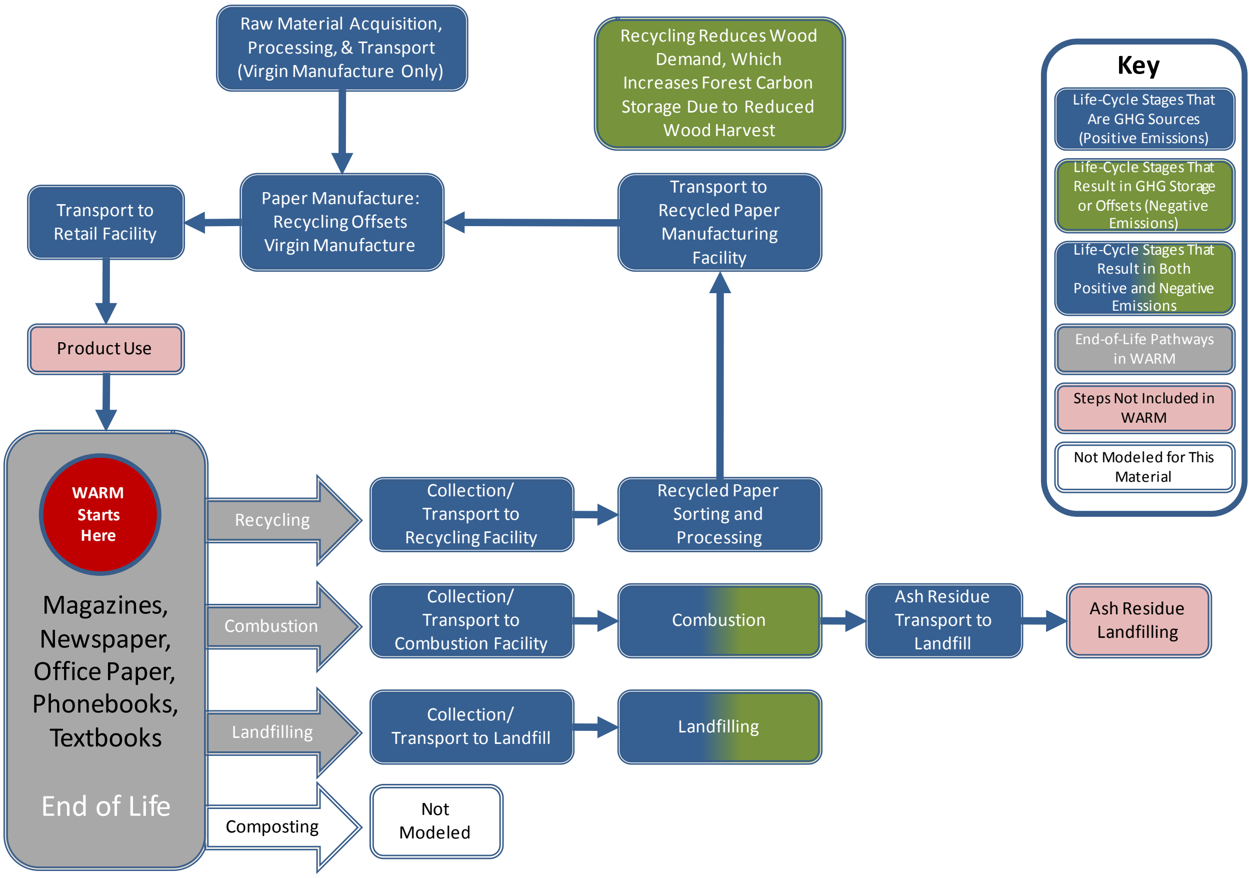
Corrugated containers are boxes made from containerboard (liner and corrugating medium) used in packaging applications (EPA, 2006). Exhibit 1 shows the general outline of materials management pathways for corrugated containers in WARM.

Exhibit 1: Life Cycle of Corrugated Containers in WARM



Third Class Mail is now called Standard Mail by the U.S. Postal Service and includes catalogs and other direct bulk mailings such as magazines, which are made of coated, shiny paper (EPA, 2006). The magazines/third-class mail category represents coated paper produced from mechanical pulp. Newspaper represents uncoated paper made from 70 percent mechanical pulp and 30 percent chemical pulp (FAL, 1998a). Office paper refers to the type of paper used in computer printers and photocopiers (EPA, 2006) and represents paper made from uncoated bleached chemical pulp (FAL, 1998b). Phonebooks represent telephone books that are made from paper produced from mechanical pulp (EPA, 2006). Textbooks represent books made from paper produced from chemical pulp (EPA, 2006). Exhibit 2 shows the general outline of materials management pathways for magazines/third-class mail, newspaper, office paper, phone books and textbooks in WARM.

Exhibit 2: Life Cycle of Magazines/Third-Class Mail, Newspaper, Office Paper, Phonebooks and Textbooks in WARM



Mixed paper is recycled in large quantities and is an important class of scrap material in many recycling programs. Presenting a single definition of mixed paper is difficult, however, because recovered paper varies considerably, depending on the source. For purposes of WARM, we identified three categories of mixed paper according to the dominant source: (1) general, (2) primarily residential and (3) primarily from offices. General mixed paper includes almost all printing-writing paper, folding boxes, and most paper packaging. Primarily residential mixed paper includes high-grade office paper, magazines, catalogues, commercial printing, folding cartons and a small amount of old corrugated containers. Mixed paper primarily from offices includes copier and printer paper, stationary and envelopes, and commercial printing.

Exhibit 3 shows the composition of mixed paper categories assumed by WARM. EPA uses the compositions of mixed paper as defined by FAL (1998b). This document presents data specific to the composition of mixed paper recycled to produce boxboard and tissue paper, which are the recycling pathways modeled by WARM (read more in section 4.2).

Exhibit 3: Composition of Mixed Paper Categories

Paper Grade	Mixed Paper (General)	Mixed Paper (Primarily Residential)	Mixed Paper (Primarily from Offices)
Corrugated Containers	48%	53%	5%
Magazines/Third-Class Mail	8%	10%	36%
Newspaper	24%	23%	21%
Office Paper	20%	14%	38%
Total	**100%**	**100%**	**100%**

Because the data in FAL (1998b) is more than 10 ten years old, EPA compared the percentages used in WARM for the general mixed paper definition to paper products recovery numbers presented in EPA's *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007* (EPA, 2008). EPA used the detailed characterization of mixed paper generation in Table 4 of the *Facts and Figures* report and assigned proxies to each of the product categories using the four paper grades tested by Dr. Barlaz.[1] Exhibit 4 presents the results of this analysis, which shows that the composition of mixed paper assumed in WARM is similar to the data presented in EPA's *Facts and Figures for 2007* report. Due to the changing composition of mixed paper and the fact that the FAL data is more than 10 years old, EPA may consider revising the mixed paper composition definitions in future WARM updates.

Exhibit 4: Comparison of WARM Mixed Paper (General) Definition to EPA Facts and Figures

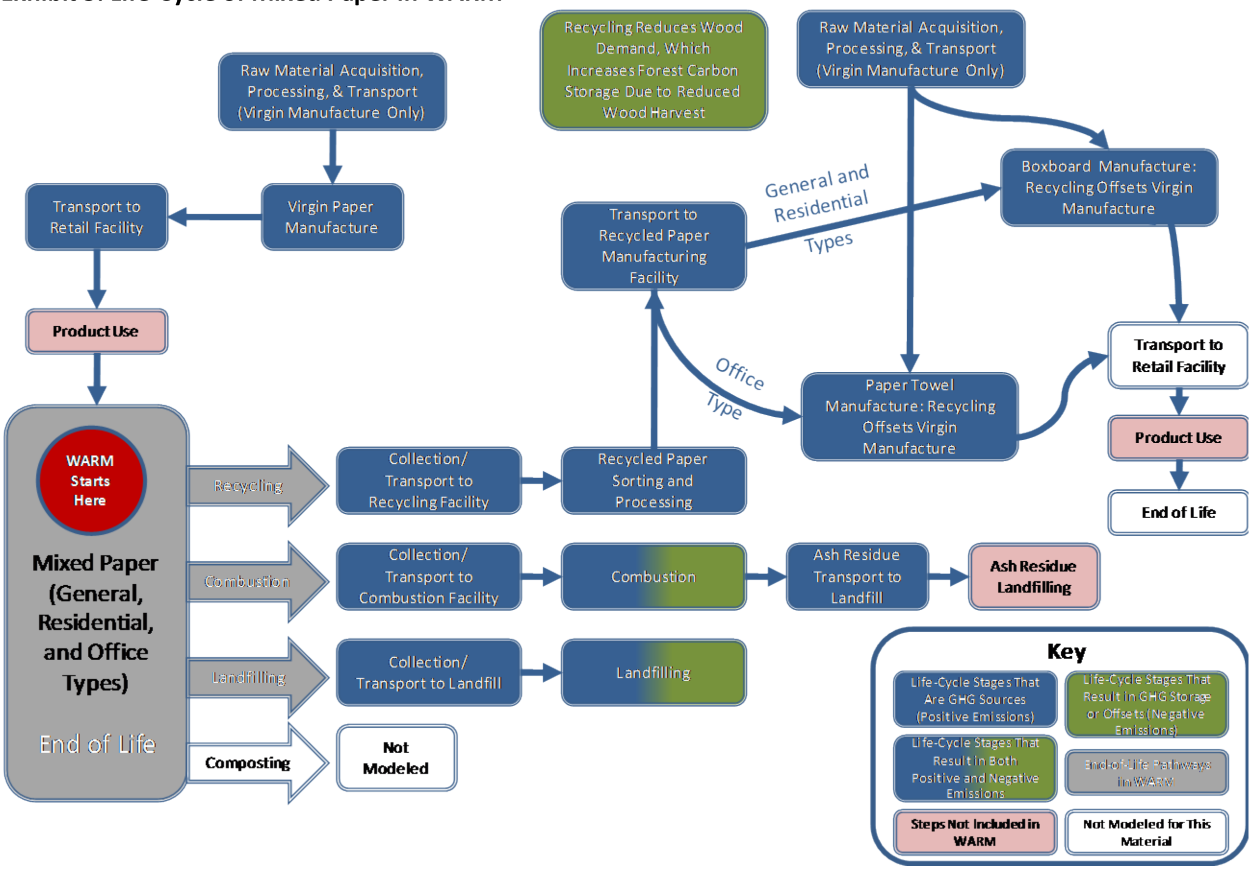
Paper Grade	WARM: Mixed Paper (General)	EPA Facts and Figures
Corrugated Containers	48%	49%
Magazines/Third-Class Mail	8%	10%
Newspaper	24%	14%
Office Paper	20%	27%
Total	**100%**	**100%**

Source: EPA (2008).

Exhibit 5 shows the general outline of materials management pathways for the three definitions of mixed paper in WARM.

[1] The corrugated containers category was used to proxy tissue paper and towels, paper plates and cups, other nonpackaging paper and corrugated boxes. The magazines/third-class mail category was used to proxy magazines and standard mail. Newspaper was used to proxy newsprint, groundwood inserts and telephone directories. Office paper was used to proxy books, office-type papers, other commercial printing, milk cartons, folding cartons, other paperboard packaging, bags and sacks, and other paper packaging.

Exhibit 5: Life-Cycle of Mixed Paper in WARM



According to EPA's report, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2010* (EPA, 2011a), paper products accounted for 28.5 percent of total municipal solid waste (MSW) generation in 2010. Recent figures on paper and paperboard generation and recovery are shown in Exhibit 6.

Exhibit 6: U.S. Paper and Paperboard Generation and Recovery in 2008

Material/Product	Generation (Short Tons)	Recovery (Short Tons)	Total MSW Generation (Short Tons)	Paper as % of Total MSW
Paper and Paperboard	71,310,000	44,570,000	249,860,000	28.5%

Source: EPA (2011a).

2. LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The life-cycle boundaries in WARM start at the point of waste generation—the point at which a material is discarded—and only consider upstream (i.e., material acquisition and manufacturing) GHG emissions when the production of new materials is affected by materials management decisions. Recycling and source Reduction are the two materials management options that impact the upstream production of materials, and consequently are the only management options that include upstream GHG emissions. For more information on evaluating upstream emissions, see the chapters on Recycling, and Source Reduction.

Although paper can be composted, composting is not currently included as a materials management pathway for paper products because the composting factor in WARM, described in the

Composting chapter, assumes a generic compost mix, rather than looking at materials in isolation. It is not currently known what effect adding large amounts of paper would have at a composting site, including whether the GHG emissions/sequestration would be altered or whether the carbon/nitrogen ratio would be affected. WARM also does not include source reduction as a materials management pathway for the three mixed paper types, because mixed paper is not a product itself and therefore cannot be source reduced. Rather, mixed paper is a collection of other products, each of which can be source reduced individually. Exhibit 7 illustrates the GHG sources and offsets that are relevant to paper products in this analysis.

Exhibit 7: Paper Products GHG Sources and Sinks from Relevant Materials Management Pathways

Waste Management Strategies for Paper Products	GHG Sources and Sinks Relevant to Paper Products		
	Raw Materials Acquisition and Manufacturing	**Changes in Forest or Soil Carbon Storage**	**End of Life**
Source Reduction	**Offsets** • Transport of raw materials and intermediate products • Virgin process energy and non-energy • Transport of paper products to point of sale	**Offsets** • Increase in forest carbon storage	NA
Recycling	**Emissions** • Transport of recycled materials • Recycled process energy and non-energy **Offsets** • Transport of raw materials and intermediate products • Virgin process energy and non-energy • Transport of paper products to point of sale	**Offsets** • Increase in forest carbon storage	**Emissions** • Collection of paper products and transportation to recycling center
Composting	Not Modeled in WARM		
Combustion	NA	NA	**Emissions** • Transport to WTE facility • Combustion-related N_2O **Offsets** • Avoided utility emissions
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery **Offsets** • Carbon storage in landfill • Energy recovery

NA = Not applicable.

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 7 and calculates net GHG emissions per short ton of inputs, shown in Exhibit 8 for the four materials management pathways. For more detailed methodology on emission factors, please see sections 4.1, 4.2, 4.3, 4.4, and 4.5.

Exhibit 8: Net Emissions for Paper Products under Each Materials Management Option ($MTCO_2E$/Short Ton)

Material/Product	Net Source Reduction (Reuse) Emissions For Current Mix of Inputs	Net Recycling Emissions	Net Composting Emissions	Net Combustion Emissions	Net Landfilling Emissions
Corrugated Containers	-5.59	-3.11	NA	-0.48	-0.05
Magazines/Third-Class Mail	-8.64	-3.07	NA	-0.35	-0.47
Newspaper	-4.85	-2.78	NA	-0.55	-1.01
Office Paper	-7.99	-2.85	NA	-0.47	1.17
Phone Books	-6.27	-2.65	NA	-0.55	-1.01
Textbooks	-9.11	-3.11	NA	-0.47	1.17
Mixed Paper (general)	NA	-3.52	NA	-0.49	-0.07
Mixed Paper (primarily residential)	NA	-3.52	NA	-0.48	-0.14
Mixed Paper (primarily from offices)	NA	-3.59	NA	-0.44	0.06

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
NA = Not applicable.

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

GHG emissions associated with raw materials acquisition and manufacturing (RMAM) from the manufacturing of paper products are (1) GHG emissions from energy used during the RMAM processes, (2) GHG emissions from energy used to transport materials, and (3) non-energy GHG emissions resulting from manufacturing processes. In paper product manufacture, non-energy process emissions result primarily from the conversion of limestone ($CaCO_3$) into lime (CaO), which results in CO_2 emissions (EPA, 2006).

Paper pulp production can be categorized generally into two methods: chemical pulp manufacture and mechanical pulp manufacture.

There are many different chemical pulping methods, including kraft, sulfite and semichemical (FAL, 1998a). In the chemical pulp process, wood fibers are isolated by removing the surrounding lignin in the wood raw material. Wood chips are delivered to the mill, washed and screened. Then the chips are heated with water and chemicals to break down the lignin, resulting in long fibers (VDP, 2008).The chips are softened and brightened by impregnation with sodium sulfite, which also aids in fiber separation. The resulting pulp undergoes several stages of refining, screening, cleaning and filtering to remove undesirable particles from the pulp. At this stage, pulp can be bleached using chlorine dioxide, along with other chemicals. After bleaching, the pulp is mechanically dewatered using filters and roll presses. The final pulp drying operation involves circulating hot air over the pulp in a series of columns (VDP, 2008).

Mechanical pulping is a process in which fibers are physically separated from the wood raw material (VDP, 2008). Mechanical pulp production includes groundwood pulp production and refiner mechanical pulp production. Because data on refiner mechanical pulp production, which uses a disc refiner to break down wood chips, are not available, the data for mechanical pulp represent only the stone groundwood process. In the groundwood pulp production process, pulp is produced by pressing blocks of wood against an abrasive rotating stone surface. Few to no chemicals are used in this process (FAL, 1998a).

Corrugated containerboard is produced by gluing a fluted corrugating medium between two linerboards. Corrugated containers are typically 68 percent linerboard and 32 percent corrugating medium by weight. Both the linerboard and corrugating medium typically contain recycled content. RMAM processes for corrugated containers include roundwood harvesting,[2] wood residues production, limestone mining, salt mining, caustic soda production, sulfur production, sodium sulfate mining and processing, sulfuric acid production, unbleached virgin kraft paper production, old corrugated container collection, recycled medium and linerboard production, semichemical paper production, soda ash production, starch adhesives, corrugated container manufacture and folding box manufacture (FAL, 1998a).

Approximately 12 percent of newsprint is composed of continuously recycled pulp from recovered newspapers. The majority of newsprint pulp is from virgin pulp. The virgin pulp is made from approximately 70 percent mechanical pulp and 30 percent chemical pulp. RMAM processes involved in the production of newsprint include roundwood harvesting, wood residues production, salt mining, caustic soda and chlorine production, sodium chlorate production, limestone mining, sulfur production, bleached chemical pulp manufacture, mechanical pulp manufacture, newsprint production and ink manufacture. Approximately 53 percent of wood delivered to paper mills comes from trees harvested specifically for wood pulp production, while the remainder comes from wood residues generated by lumber production or other wood processing operations. After the wood is pulped, pulps are mixed and combined with water in the stock storage chest to form a suspension. This suspension is mechanically dewatered and pressed using wire mesh, synthetic felt and vacuum boxes. Once dry, the paper is softened, smoothed and wound onto a large, bulk size reel, or parent roll. Any broke, or scrap generated in the papermaking process, is collected to be repulped (FAL, 1998a).

Office paper manufacture involves the following RMAM processes: roundwood harvesting, wood residues production, salt mining, caustic soda and chlorine production, sodium chlorate production, limestone mining, sulfur production, mechanical pulp manufacture, bleached virgin kraft pulp production and paper production. Office paper production involves draining the dilute pulp suspension onto a finely woven plastic or wire mesh belt. Draining and pressing the fiber web between hard machine rolls removes approximately 98 percent of the excess water. Final excess water is evaporated using steam-heated drums. The paper is then wound onto rolls. The rolls are then cut and packaged into reams[3] (FAL, 1998a).

Paper used in magazines/third-class mail is composed of a mix of mechanically and chemically pulped paper, which has then been treated to give it a shiny appearance. This treatment involves coating the raw paper with substances including pigments, binders and sealing coats. The paper is further smoothed through a process called the “supercalender,” where the paper runs between several rollers of varying hardness and material, making the paper smooth and glossy through an “ironing effect” (VDP, 2008). Phone books and textbooks are bound books with covers. Phone books are made with mechanical pulp, similar to newspapers. Textbooks are made with chemical pulp, similar to office paper.

The RMAM calculation in WARM also incorporates “retail transportation,” which is the average emissions from truck, rail, water and other-modes transportation required to transport paper products from the manufacturing facility to the retail/distribution point, which may be the customer or a variety of other establishments (e.g., warehouse, distribution center, wholesale outlet). Transportation emissions from the retail point to the consumer are not included in WARM. The energy and GHG

[2] Harvested logs, with or without bark. Roundwood may be round, spilt or roughly squared (FAO, 1997).
[3] The life-cycle process description of office paper provided in FAL (1998a) is inclusive of winding the paper onto rolls after the drying section, but does not include the final step of cutting and packing into reams.

emissions from retail transportation are presented in Exhibit 9. The number of miles traveled is obtained from the 2007 *U.S. Census Commodity Flow Survey* (BTS, 2007) and mode-specific fuel use is from *Greenhouse Gas Emissions from the Management of Selected Materials* (EPA, 1998a).

Exhibit 9: Retail Transportation Energy Use and GHG Emissions for Paper Products

Material/Product	Average Miles per Shipment	Transportation Energy per Short Ton of Product (Million Btu)	Transportation Emission Factors ($MTCO_2E$/ Short Ton)
Corrugated Containers	392	0.42	0.03
Magazines/Third-Class Mail	250	0.27	0.02
Newspaper	250	0.27	0.02
Office Paper	250	0.27	0.02
Phone Books	546	0.59	0.04
Textbooks	546	0.59	0.04

4. MATERIALS MANAGEMENT METHODOLOGIES

WARM models four materials management alternatives for paper products: source reduction, recycling, combustion, and landfilling. Source reduction, recycling, and combustion result in negative emissions (net emission reductions) for all nine paper products and mixed paper categories, while landfilling results in negative emissions for three of the nine products. As shown in Exhibit 8, source reducing paper products is the most beneficial management strategy overall.

WARM also calculates an emission factor for producing paper products from “virgin” inputs. For all paper products except corrugated containers, virgin production is from 100 virgin inputs. Corrugated containers, however, are rarely manufactured from 100 percent virgin inputs. Exhibit 10 shows the range of recycled content used for manufacturing paper products (FAL, 2003a). Since the minimum recycled content for corrugated containers is 9.8 percent, “virgin” corrugated cardboard as referred to in the rest of this chapter is assumed to contain 9.8 percent recycled inputs.

Exhibit 10: Typical Paper Products Recycled Content Values in the Marketplace

Material/Product	Recycled Content Minimum	Recycled Content Maximum
Corrugated Containers	9.8%	75%
Magazines/Third-Class Mail	0.0%	30%
Newspaper	0.0%	60%
Office Paper	0.0%	35%
Phone Books	0.0%	10%
Textbooks	0.0%	15%

The current mix of recycled and virgin inputs used for manufacturing each paper product is provided in Exhibit 11. The emission factors for source reduction and recycling are affected by the mix of inputs used for the manufacturing process. The emission factors for paper products produced from the current mix of virgin and recycled inputs are calculated using a weighted average of virgin and recycled paper products production data, based on the values in Exhibit 11 (FAL, 2003a).

Exhibit 11: Current Mix of Inputs for Paper Products Manufacturing

Material/Product	% of Current Production from Recycled Inputs	% of Current Production from "Virgin" Inputs
Corrugated Containers	35%	65%
Magazines/Third-Class Mail	4%	96%
Newspaper	23%	77%
Office Paper	4%	96%
Phone Books	0%	100%
Textbooks	4%	96%
Mixed Paper (general)	23%	77%

Mixed Paper (primarily residential)	25%	75%
Mixed Paper (primarily from offices)	10%	90%

4.1 SOURCE REDUCTION

Source reduction activities reduce the quantity of paper products manufactured, reducing the GHG emissions associated with making the material and managing the post-consumer waste. Printing on both sides of office paper is one example of source reduction for paper products. For more information on source reduction in general, see the Source Reduction chapter.

Exhibit 12 provides the breakdown of the GHG emissions factors for source reduction of paper products. GHG benefits of source reduction are calculated as the avoided emissions from RMAM of each product. The GHG emission sources and sinks from source reduction include:

Process energy, transportation and non-energy process GHG emissions. Producing paper products results in GHG emissions from energy consumption in manufacturing processes and transportation, as well as non-energy-related CO_2 emissions in the production of lime from limestone.

Carbon storage. Reducing the quantity of paper products manufactured results in increased forest carbon stocks from marginal changes in the demand for virgin pulpwood. For more information, see the Forest Carbon Storage chapter.

Exhibit 12: Source Reduction Emission Factors for Paper Products ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing for Current Mix of Inputs	Raw Material Acquisition and Manufacturing for 100% Virgin Inputs	Forest Carbon Storage for Current Mix of Inputs	Forest Carbon Storage for 100% Virgin Inputs	Net Emissions for Current Mix of Inputs	Net Emissions for 100% Virgin Inputs
Corrugated Containers	-0.87	-0.84	0.00	-4.73	-7.26	-5.59
Magazines/Third -Class Mail	-1.67	-1.67	0.00	-6.96	-7.26	-8.64
Newspaper	-1.90	-2.10	0.00	-2.95	-3.83	-4.85
Office Paper	-1.03	-1.01	0.00	-6.96	-7.26	-7.99
Phone Books	-2.43	-2.43	0.00	-3.83	-3.83	-6.27
Textbooks	-2.15	-2.15	0.00	-6.96	-7.26	-9.11

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.

Developing the Emission Factor for Source Reduction of Paper Products

To calculate the avoided GHG emissions for paper products, EPA first looks at three components of GHG emissions from RMAM activities: process energy, transportation energy and non-energy GHG emissions. Exhibit 13 shows the results for each component and the total GHG emission factors for source reduction of paper products. More information on each component making up the final emission factor is provided in the remainder of this section. The methodology for estimating emissions from paper products manufactured from recycled materials is discussed in the Recycling section (4.2).

Exhibit 13: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Paper Products ($MTCO_2E$/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
Corrugated Containers[a]	0.70	0.13	0.01	0.84
Magazines/Third-Class Mail	1.65	0.02	–	1.67
Newspaper	2.04	0.06	–	2.10
Office Paper	0.97	0.02	0.03	1.01
Phone Books	2.39	0.04	–	2.43
Textbooks	2.11	0.04	–	2.15
Mixed Paper (general)	1.05	0.13	0.01	1.19
Mixed Paper (primarily residential)	1.05	0.13	0.01	1.19
Mixed Paper (primarily from offices)	3.12	0.15	0.01	3.28

– = Zero emissions.

[a] "Virgin" corrugated containers include a minimum recycled content of 9.8 percent; see section 4.

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.

To calculate this factor, EPA obtained an estimate of the amount of energy, by fuel type, required to acquire and produce one short ton of each paper product, in Btu (RTI, 2004). Next, we multiplied the fuel consumption (in Btu) by the fuel-specific carbon content as outlined by EPA (EPA, 2011b). The sums of the resulting GHG emissions by fuel type comprise the total process energy GHG emissions from all fuel types used in paper production. The process energy used to produce paper products and the resulting emissions are shown in Exhibit 14.

Exhibit 14: Process Energy GHG Emissions Calculations for Virgin Production of Paper Products

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Process Energy GHG Emissions ($MTCO_2E$/Short Ton)
Corrugated Containers	25.13	0.70
Magazines/Third-Class Mail	32.99	1.65
Newspaper	39.92	2.04
Office Paper	37.01	0.97
Phone Books	39.61	2.39
Textbooks	35.07	2.11

Transportation energy emissions occur when fossil fuels are used to transport raw materials and intermediate products for paper products production. The methodology for estimating these emissions is the same as used for process energy emissions. Based on estimated transportation energy by fuel type (RTI, 2004), EPA calculates the total emissions using fuel-specific carbon coefficients (EPA, 2011b). Transportation energy also includes "retail transportation," as described in section 3. The transportation energy used to produce paper products and the resulting emissions are shown in Exhibit 15.

Exhibit 15: Transportation Energy Emissions Calculations for Virgin Production of Paper Products

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy GHG Emissions ($MTCO_2E$/Short Ton)
Corrugated Containers	1.31	0.10
Magazines/Third-Class Mail	NA	NA
Newspaper	0.50	0.04
Office Paper	NA	NA
Phone Books	NA	NA
Textbooks	NA	NA

NA = Not applicable.

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 9.

Non-energy GHG emissions occur during manufacturing, but are not related to consuming fuel for energy. For corrugated containers and newspaper, non-energy CO_2 emissions are based on data from RTI (2004). For office paper, non-energy CO_2 emissions are based on the original analysis supporting the first edition of this report (ICF, 1994). Exhibit 16 shows the components for estimating process non-energy GHG emissions for paper products.

Exhibit 16: Process Non-Energy Emissions Calculations for Virgin Production of Paper Products

Material/Product	CO_2 Emissions (MT/Short Ton)	CH_4 Emissions (MT/Short Ton)	CF_4 Emissions (MT/Short Ton)	C_2F_6 Emissions (MT/Short Ton)	N_2O Emissions (MT/Short Ton)	Non-Energy Carbon Emissions ($MTCO_2E$/Short Ton)
Corrugated Containers	0.01	–	–	–	–	0.01
Magazines/Third-Class Mail	–	–	–	–	–	–
Newspaper	–	–	–	–	–	–
Office Paper	0.03	–	–	–	–	0.03
Phonebooks	–	–	–	–	–	–
Textbooks	–	–	–	–	–	–

– = Zero emissions.

In addition to RMAM emissions, source reduction of paper affects the amount of carbon forest stored in managed forests. By reducing the quantity of paper products manufactured, source reduction reduces the number of trees harvested relative to what would have been harvested without source reducing paper. By preserving trees that would have otherwise been harvested, source reduction increases the amount of carbon stored in the forest. The change in carbon storage per unit of paper source reduction for each paper type is shown in Exhibit 17. For the carbon storage portion of the newspaper emission factor, EPA assumes, in order to be conservative, that the paper was all mechanical pulp. For more information, see the Forest Carbon Storage chapter.

Exhibit 17: Forest Carbon Storage from Source Reduction of Paper Products

(a) Material/Product	(b) Pulp Type	(c) Reduction in Timber Harvest per Unit of Increased Source Reduction (Short Tons Timber/Short Ton of Paper)	(d) Change in Forest C Storage per Unit Reduced Timber Harvest (Metric Tons Forest C/Metric Ton Timber)	(e) Net Change in C Storage per Unit of Increased Source Reduction, 100% Virgin Inputs ($MTCO_2E$/Short Ton) (e = c × d × 0.907)	(f) Percent Virgin Inputs in the Current Mix of Inputs	(g) Net Change in C Storage per Unit of Increased Source Reduction, Current Mix ($MTCO_2E$/Short Ton) (g = e × f)
Corrugated Cardboard	Chemical	2.11	1.04	7.26	65.1%	4.73
Magazines/Third-Class Mail	Chemical	2.11	1.04	7.26	95.9%	6.96
Newspaper	Mechanical	1.11	1.04	3.83	77.0%	2.95
Office Paper	Chemical	2.11	1.04	7.26	95.9%	6.96
Phone Books	Mechanical	1.11	1.04	3.83	100.0%	3.83
Textbooks	Chemical	2.11	1.04	7.26	95.9%	6.96

One metric ton = 0.907 short tons.

4.2 RECYCLING

In order to use pulp recovered from industrial scrap or post-consumer paper products, recovered fiber sources must undergo deinked recovered pulp manufacture. To do this, recovered fiber sources must first be repulped. During this step, large-sized contaminants are separated from the fiber. Smaller-sized contaminants are then screened for removal. If inks are present, a portion of the inks, as well as some coatings and fillers, are washed from the fiber during the screening process. This may be sufficient for some applications, such as combination paperboard. If higher brightness is needed for the final product, additional inks, fillers and coatings are removed using a washing and/or flotation process involving chemical digestion "cooking." This process results in a significant weight loss of fiber as deinking sludge. The deinked pulp is then dried or partially dried before delivery to a paper mill. Other processes required for recycled paper product production include collection of used paper products, and recycled medium and linerboard production for corrugated containers (FAL, 1998a).

Most paper products are modeled as being recycled in a closed loop (e.g., old newspaper is recycled into new newspaper). Magazines/third-class mail, newspaper, office paper, phone books and textbooks are all assumed to be recycled in a closed-loop cycle. The recycling pathway for these paper types is modeled in Exhibit 2.

The three mixed paper types are modeled as being recycled in an open loop. Mixed paper is used in this way because of the quality constraints resulting from a broad mixture of paper types that include newsprint, office paper, coated paper and corrugated containerboard. The pulp fibers obtained from mixed paper are not well-suited for use in producing the materials they were generated from; rather, they are well-suited for lower-grade paper products such as cardboard. For the purposes of this methodology, EPA assumes that 100 percent of the general and residential mixed paper is remanufactured into recycled boxboard. Recycled boxboard is kraft unbleached paperboard that is used for the manufacture of folding cartons and rigid boxes. Although recycled boxboard is modeled as an open-loop recycling pathway in WARM, it is not included as a separate paper type in WARM because it is composed of 100 percent recycled inputs. EPA assumes that mixed paper from offices is remanufactured into tissue paper, which is used in toilet tissue, facial tissue and commercial paper towels. Therefore, the GHG benefits of mixed paper recycling result from the avoided emissions associated with the manufacture of the secondary products (boxboard, tissue paper) that the material is recycled into (since the recycling would affect only the production of the secondary products). To calculate the GHG benefits of recycling mixed paper as outlined in the steps below, EPA compares the difference in emissions associated with manufacturing one ton of each of the secondary products from virgin versus recycled materials, rather than from the mixed paper itself. More information on open-loop recycling is available in the Recycling chapter. The recycling pathway for the mixed paper types is modeled in Exhibit 5.

EPA assumes that corrugated containers are recycled in a partial open loop, where 76 percent of recycled corrugated containers are used to produce boxboard and the remaining 24 percent are used to produce new corrugated containers. For corrugated containers, the results for each of the secondary products (boxboard, corrugated containers) are weighted by the appropriate material-flow distribution to obtain a composite emission factor. The recycling pathway for corrugated containers is modeled in Exhibit 1.

A "recycled input credit," which represents the net change in GHG emissions from process energy, transportation energy and process non-energy sources in recycling paper products relative to virgin production of paper products is calculated for each of the paper products. This is done by assuming that the recycled material avoids—or offsets—the GHG emissions associated with producing the paper products from virgin inputs. GHG emissions associated with management (i.e., collection, transportation and processing) of recycled paper products are included in the recycling credit calculation. In addition, there are forest carbon storage benefits associated with recycling. Each component of the recycling emission factor, as provided in Exhibit 18, is discussed further below. For more information on recycling in general, see the Recycling chapter.

Exhibit 18: Recycling Emission Factor for Paper Products ($MTCO_2E$/Short Ton)

Material/Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Materials Management Emissions	Recycled Input Credit[a] Process Energy	Recycled Input Credit[a] – Transportation Energy	Recycled Input Credit[a] – Process Non-Energy	Forest Carbon Sequestration	Net Emissions (Post-Consumer)
Corrugated Containers	–	–	0.01	-0.05	-0.01	-3.06	-3.11
Magazines/Third-Class Mail	–	–	-0.01	–	–	-3.06	-3.07
Newspaper	–	–	-0.74	-0.03	–	-2.02	-2.78
Office Paper	–	–	0.22	–	–	-3.06	-2.85
Phone Books	–	–	-0.63	–	–	-2.02	-2.65
Textbooks	–	–	-0.05	–	0.00	-3.06	-3.11
Mixed Paper (general)	–	NA	-0.35	-0.11	-0.01	-3.06	-3.52
Mixed Paper (primarily residential)	–	NA	-0.35	-0.11	-0.01	-3.06	-3.52
Mixed Paper (primarily from offices)	–	NA	-0.43	-0.11	0.00	-3.06	-3.59

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.
[a] Includes emissions from the initial production of the material being managed.

4.2.1 Developing the Emission Factor for Recycling of Paper Products

EPA calculates the GHG benefits of recycling paper products by taking the difference between producing paper products from virgin inputs and producing paper products from recycled inputs, after accounting for material losses that occur during the recycling process. This difference is the "recycled input credit."

To calculate each component of the recycling emission factor, EPA follows six steps, which are described in detail below:

Step 1. *Calculate emissions from virgin production of one short ton of paper products.* The GHG emissions from virgin production of paper products are provided in Exhibit 14, Exhibit 15, and Exhibit 16.

Step 2. *Calculate GHG emissions for recycled production of paper products.* Exhibit 19, Exhibit 20, and Exhibit 21 provide the process, transportation and non-energy process emissions associated with producing recycled paper products. Data on these energy requirements and the associated emissions are from FAL (1998a, 1998b) and are calculated using the same approach as was used for virgin manufacture, explained in section 4.1.1.

Exhibit 19: Process Energy GHG Emissions Calculations for Recycled Production of Paper Products

Material/Product	Process Energy per Short Ton Made from Recycled Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
Corrugated Containers	11.73	0.84
Magazines/Third-Class Mail	31.97	1.63
Newspaper	21.98	1.22
Office Paper	20.12	1.33
Phone Books	22.02	1.46
Textbooks	33.51	2.03
Mixed Paper (general)	11.91	0.67
Mixed Paper (primarily residential)	11.91	0.67
Mixed Paper (primarily from offices)	51.69	2.64

Exhibit 20: Transportation Energy GHG Emissions Calculations for Recycled Production of Paper Products

Material/Product	Transportation Energy per Ton Made from Recycled Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton)
Corrugated Containers	0.80	0.06
Magazines/Third-Class Mail	NA	–
Newspaper	0.03	0.00
Office Paper	NA	–
Phone Books	NA	–
Textbooks	NA	–
Mixed Paper (general)	0.23	0.02
Mixed Paper (primarily residential)	0.23	0.02
Mixed Paper (primarily from offices)	0.44	0.03

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 9

Exhibit 21: Process Non-Energy Emissions Calculations for Recycled Production of Paper Products

Material/Product	CO_2 Emissions (MT/Short Ton)	CH_4 Emissions (MT/Short Ton)	CF_4 Emissions (MT/Short Ton)	C_2F_6 Emissions (MT/Short Ton)	N_2O Emissions (MT/Short Ton)	Non-Energy Carbon Emissions ($MTCO_2E$/ Short Ton)
Corrugated Containers	–	–	–	–	–	–
Magazines/Third-Class Mail	–	–	–	–	–	–
Newspaper	–	–	–	–	–	–
Office Paper	–	–	–	–	–	–
Phone Books	–	–	–	–	–	–
Textbooks	–	–	–	–	–	–
Mixed Paper (general)	–	–	–	–	–	–
Mixed Paper (primarily residential)	–	–	–	–	–	–
Mixed Paper (primarily from offices)	0.01	0.00	–	–	–	0.01

– = Zero emissions.

Step 3. *Calculate the difference in emissions between virgin and recycled production.* To calculate the GHG emissions implications of recycling one short ton of paper products, WARM subtracts the recycled product emissions (calculated in Step 2) from the virgin product emissions (calculated in Step 1) to get the GHG savings. These results are shown in Exhibit 22.

Exhibit 22: Differences in Emissions between Recycled and Virgin Paper Products Manufacture ($MTCO_2E$/Short Ton)

	Product Manufacture Using 100% Virgin Inputs ($MTCO_2E$/Short Ton)			Product Manufacture Using 100% Recycled Inputs ($MTCO_2E$/Short Ton)			Difference Between Recycled and Virgin Manufacture ($MTCO_2E$/Short Ton)		
Material/Product	Process Energy	Transportation Energy	Process Non-Energy	Process Energy	Transportation Energy	Process Non-Energy	Process Energy	Transportation Energy	Process Non-Energy
Corrugated Containers	0.70	0.13	0.01	0.84	0.09	–	0.14	-0.04	-0.01
Magazines/Third-Class Mail	1.65	0.02	–	1.63	0.02	–	-0.02	–	–
Newspaper	2.04	0.06	–	1.22	0.02	–	-0.82	-0.03	–
Office Paper	0.97	0.02	0.03	1.33	0.02	–	0.36	–	-0.03
Phone Books	2.39	0.04	–	1.46	0.04	–	-0.93	–	–
Textbooks	2.11	0.04	–	2.03	0.04	–	-0.08	–	–
Mixed Paper (general)	1.05	0.13	0.01	0.67	0.02	–	-0.37	-0.12	-0.01
Mixed Paper (primarily residential)	1.05	0.13	0.01	0.67	0.02	–	-0.37	-0.12	-0.01
Mixed Paper (primarily from offices)	3.12	0.15	0.01	2.64	0.03	0.01	-0.48	-0.12	0.00

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.

Step 4. *Adjust the emissions differences to account for recycling losses.* When any material is recovered for recycling, some portion of the recovered material is unsuitable for use as a recycled input.

This portion is discarded either in the recovery stage or in the remanufacturing stage. Consequently, less than 1 short ton of new material generally is made from 1 short ton of recovered material. Material losses are quantified and translated into loss rates. The recycled input credits calculated above are therefore adjusted to account for any loss of product during the recycling process. The difference between virgin and recycled manufacture is multiplied by the product's net retention rate (i.e., material that is not lost during recycling, equal to the inverse of the loss rate) (FAL, 2003b; RTI, 2004), which is calculated as follows:

Net Retention Rate for Paper Products = Recovery Stage Retention Rate × Manufacturing Stage Retention Rate

Exhibit 23 shows the retention rate calculations for each of the paper products.

Exhibit 23: Paper Products Retention Rate Calculation

Material/Product	Recovery Stage Retention Rate	Manufacturing Stage Retention Rate	Net Retention Rate
Corrugated Containers	100.0%	93.5%	93.5%
Magazines/Third-Class Mail	95.0%	70.9%	67.4%
Newspaper	95.0%	94.3%	89.5%
Office Paper	91.0%	65.6%	59.7%
Phone Books	95.0%	71.4%	67.9%
Textbooks	95.0%	69.4%	66.0%

Step 5. *Calculate the net change in carbon storage associated with recycling paper products.* These adjusted credits are then combined with the estimated forest carbon sequestration from recycling paper products to calculate the final GHG emission factor for recycling. EPA estimates forest carbon storage in paper products, involving two parameters, as explained in the Forest Carbon Storage chapter. The two parameters are:

- The change in timber harvests resulting from increased recycling of paper products and
- The change in forest carbon storage as a result of a reduction in timber harvests.

The net change in carbon storage for mechanical and chemical pulp papers is shown in Exhibit 24. For the carbon storage portion of the newspaper factor, it was assumed that the paper was all mechanical pulp. Since paper products are non-durable goods, WARM does not consider changes in the in-use product carbon pool, as these products have shorter lifetimes (typically less than three years) and the carbon contained within these goods cycles out of the in-use pool over a relatively short period. For more information on forest carbon storage and each component of the overall factor, see the Forest Carbon Storage chapter.

Exhibit 24: Net Change in Carbon Storage per Unit of Increased Paper Product Recycling

(a) Pulp Type Recycled	(b) Reduction in Timber Harvest per Unit of Increased Recycling (Short Tons Timber/Short Ton of Wood)	(c) Change in Forest C Storage per Unit of Reduced Timber Harvest (Metric Tons Forest C/Metric Ton Timber)	(d) Change in C Storage in In-Use Products per Unit of Increased Paper Product Recycling ($MTCO_2E$/Short Ton)	(e) Net Change in C Storage per Unit of Increased Paper Product Recycling ($MTCO_2E$/Short Ton) (e = b × c × 0.907 + d)
Mechanical Pulp	0.58	1.04	NA	2.02
Chemical Pulp	0.89	1.04	NA	3.06

Step 6. *Calculate the net GHG emission factor for recycling paper products.* The recycling credit calculated in Step 4 is added to the estimated forest carbon sequestration from recycling paper products calculated in Step 5 to calculate the final GHG emission factor for paper products, as shown in Exhibit 18.

4.3 COMPOSTING

Composting is not included as a materials management pathway for paper products. Although paper products are composted, the composting factor in WARM, described in the Composting chapter, assumes a generic compost mix, rather than looking at materials in isolation. It is not currently known what effect adding paper would have at a composting site, including whether the GHG emissions/sequestration would be altered or whether the carbon/nitrogen ratio would be affected.

4.4 COMBUSTION

Combusting paper products results in emissions of both carbon dioxide (CO_2) and nitrous oxide (N_2O). Because carbon in paper products is considered to be biogenic,[4] CO_2 emissions from combustion are not considered in WARM. The N_2O emissions, however, are included in WARM's GHG emission factors for paper products. Transporting paper products to combustion facilities also results in GHG emissions from the combustion of fossil fuels in vehicles. Finally, electricity produced from waste combustion energy recovery is used to offset the need for electricity production at power plants, consequently reducing the power sector's consumption of fossil fuels. WARM takes this into account by calculating an avoided utility emission offset.[5] Exhibit 25 provides the breakdown of each paper product's emission factor into these components. For additional information on combustion in WARM, see the Combustion chapter.

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[4] WARM assumes that biogenic CO_2emissions are balanced by CO_2 captured by re-growth of the plant sources of the material. Consequently, these emissions are excluded from net GHG emission factors in WARM.

[5] The utility offset credit is calculated based on the non-baseload GHG emissions intensity of U.S. electricity generation, since it is non-baseload power plants that will adjust to changes in the supply of electricity from energy recovery at landfills.

Exhibit 25: Components of the Combustion Net Emission Factor for Paper Products ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion[a]	N_2O from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
Corrugated Containers	–	0.03	–	0.04	-0.55	–	-0.48
Magazines/ Third-Class Mail	–	0.03	–	0.04	-0.41	–	-0.35
Newspaper	–	0.03	–	0.04	-0.62	–	-0.55
Office Paper	–	0.03	–	0.04	-0.53	–	-0.47
Phone Books	–	0.03	–	0.04	-0.62	–	-0.55
Textbooks	–	0.03	–	0.04	-0.53	–	-0.47
Mixed Paper (general)	–	0.03	–	0.04	-0.55	–	-0.49
Mixed Paper (primarily residential)	–	0.03	–	0.04	-0.55	–	-0.48
Mixed Paper (primarily from offices)	–	0.03	–	0.04	-0.51	–	-0.44

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.
[a] CO_2 emissions from combustion of paper products are assumed to be biogenic and are excluded from net emissions.

Exhibit 26 provides the calculation for the avoided utility emissions. EPA uses three data elements to estimate the avoided electric utility CO_2 emissions associated with combustion of waste in a WTE plant: (1) the energy content of each waste material, (2) the combustion system efficiency in converting energy in paper products to delivered electricity,[6] and (3) the electric utility CO_2 emissions avoided per kilowatt-hour (kWh) of electricity delivered by WTE plants. For more information on combustion in general, see the Combustion chapter.

Exhibit 26: Utility GHG Emissions Offset from Combustion of Paper Products

(a) Material/Product	(b) Energy Content (Million Btu per Short Ton)	(c) Combustion System Efficiency (%)	(d) Emission Factor for Utility-Generated Electricity ($MTCO_2E$/ Million Btu of Electricity Delivered)	(e) Avoided Utility GHG per Short Ton Combusted ($MTCO_2E$/Short Ton) ($e = b \times c \times d$)
Corrugated Containers	14.1	17.8%	0.22	0.55
Magazines/Third-Class Mail	10.5	17.8%	0.22	0.41
Newspaper	15.9	17.8%	0.22	0.62
Office Paper	13.6	17.8%	0.22	0.53
Phone Books	15.9	17.8%	0.22	0.62
Textbooks	13.6	17.8%	0.22	0.53

[6] EPA used a net value of 550 kWh generated by mass burn plants per ton of mixed MSW combusted (Zannes, 1997), an MSW heat content of 10 million Btu per short ton, and a 5 percent transmission and distribution loss rate.

4.5 LANDFILLING

When paper products are landfilled, anaerobic bacteria slowly degrade the materials, producing CH_4 and CO_2 over time. Because paper is derived from sustainably harvested sources of wood in the United States, CO_2 emissions are not counted, as they are biogenic and would be produced through natural decomposition in forests. CH_4 emissions, however, are included in WARM's emission factors, since the CH_4 is emitted as a result of placing the paper in a landfill, making the CH_4 a human-caused (i.e., anthropogenic) source of GHG emissions. In addition to CO_2 and CH_4 emissions, some of the carbon in landfilled paper remains stored in the landfill because paper products are not completely decomposed by anaerobic bacteria. This stored carbon constitutes a sink (i.e., negative emissions) in the net emission factor calculation. WARM also considers transportation of paper products to the landfill, which results in anthropogenic CO_2 emissions due to the combustion of fossil fuels in vehicles and landfilling equipment. Exhibit 27 provides the landfilling emission factors for paper products, broken down into these components. More information on the development of the emission factor is provided in the remainder of this section. For more information on landfilling in general, see the Landfilling chapter.

From a waste management perspective, landfilling some materials—including newspaper and phone books—results in net storage (i.e., carbon storage exceeds CH_4 plus transportation energy emissions) at all landfills, regardless of whether gas recovery is present. At the other extreme, office paper and textbooks result in net emissions regardless of landfill gas collection and recovery practices.

Exhibit 27: Landfilling Emission Factors for Paper Products ($MTCO_2E$/Short Ton)

Material/Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Landfill	Landfill CH_4	Avoided CO_2 Emissions from Energy Recovery	Landfill Carbon Storage	Net Emissions (Post-Consumer)
Corrugated Containers	–	0.04	0.82	-0.08	-0.82	-0.05
Magazines/Third-Class Mail	–	0.04	0.35	-0.03	-0.82	-0.47
Newspaper	–	0.04	0.31	-0.03	-1.33	-1.01
Office Paper	–	0.04	1.43	-0.14	-0.16	1.17
Phonebooks	–	0.04	0.31	-0.03	-1.33	-1.01
Textbooks	–	0.04	1.43	-0.14	-0.16	1.17
Mixed Paper (general)	–	0.04	0.78	-0.08	-0.81	-0.07
Mixed Paper (primarily residential)	–	0.04	0.74	-0.07	-0.84	-0.14
Mixed Paper (primarily from offices)	–	0.04	0.77	-0.08	-0.67	0.06

Note: The emission factors for landfill CH_4 presented in this table are based on national-average rates of landfill gas capture and energy recovery. Avoided CO_2 emissions from energy recovery are calculated based on the non-baseload GHG emissions intensity of U.S. electricity generation, since it is non-baseload power plants that will adjust to changes in the supply of electricity from energy recovery at landfills.
Negative values denote GHG emission reductions or carbon storage.
– = Zero emissions.

4.5.1 Developing the Emission Factor for Landfilling of Paper Products

WARM calculates CH_4 emission factors for landfilled materials based on the CH_4 collection system installed at a given landfill. As detailed in the Landfilling chapter, there are three categories of landfills modeled in WARM: (1) landfills that do not recover landfill gas (LFG), (2) landfills that collect the LFG and flare it without energy recovery, and (3) landfills that collect LFG and recover energy by combusting it to generate electricity. WARM does not model direct use of landfill gas for process heat. WARM calculates emission factors for each of these three landfill types and uses the national average mix of collection systems installed at landfills in the United States to calculate a national average emission factor that accounts for the extent to which CH_4 is not captured, is flared without energy recovery, or is combusted onsite for energy recovery.[7, 8] The Landfill CH_4 column of Exhibit 27 presents emission factors based on the national average of LFG collection usage.

The Excel version of WARM allows users to select landfill gas collection scenarios and component-specific decay rates based on different assumed moisture contents of the landfill. The tables in this section show typical landfill gas collection practices, assuming "average" (typical) moisture conditions that represent landfills that receive greater than 25 inches of precipitation annually (i.e., corresponding to an MSW decay rate of 0.04/year) (EPA, 1998b). For further explanation, see the Landfilling chapter.

Exhibit 28 depicts the specific emission factors for each landfill gas collection type. Overall, landfills that do not collect LFG produce the most CH_4 emissions.

Exhibit 28: Components of the Landfill Emission Factor for the Three Different Methane Collection Systems Typically Used In Landfills ($MTCO_2E$/Short Ton)

(a)	(b) Net GHG Emissions from CH_4 Generation			(c)	(d)	(e) Net GHG Emissions from Landfilling (e = b + c + d)		
Material/ Product	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation	Net Landfill Carbon Storage	GHG Emissions from Transport-ation	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation
Corrugated Containers	2.27	0.25	0.00	-0.82	0.04	1.49	-0.54	-0.79
Magazines/ Third-Class Mail	0.92	0.12	0.02	-0.82	0.04	0.14	-0.66	-0.76
Newspaper	0.81	0.11	0.02	-1.33	0.04	-0.48	-1.18	-1.27
Office Paper	3.83	0.48	0.07	-0.16	0.04	3.71	0.36	-0.05
Phone Books	0.81	0.11	0.02	-1.33	0.04	-0.48	-1.18	-1.27
Textbooks	3.83	0.48	0.07	-0.16	0.04	3.71	0.36	-0.05
Mixed Paper (general)	2.12	0.28	0.06	-0.81	0.04	1.35	-0.49	-0.71
Mixed Paper (primarily residential)	2.02	0.27	0.05	-0.84	0.04	1.21	-0.53	-0.75
Mixed Paper (primarily from offices)	2.07	0.40	0.20	-0.67	0.04	1.43	-0.23	-0.43

Note: Negative values denote GHG emission reductions or carbon storage.

WARM calculates landfill carbon storage from paper products based on laboratory test data on the ratio of carbon storage per short ton of paper landfilled. This estimate uses data from Barlaz (1998).

[7] Although gas from some landfills is piped to an offsite power plant and combusted there, for the purposes of this report, the assumption was that all gas for energy recovery was combusted onsite.

[8] For the year 2007, an estimated 29 percent of landfill CH4 was generated at landfills with landfill gas recovery systems and flaring, while 32 percent was generated at landfills with gas collection and energy recovery systems (EPA, 2011b).

Barlaz provides estimates for newsprint, corrugated containers and office paper. Coated paper is used as a proxy for magazines/third-class mail, newsprint is used as a proxy for phonebooks, and office paper is used as a proxy for textbooks. Exhibit 29 provides the landfill carbon storage calculation used in WARM.

Exhibit 29: Calculation of the Carbon Storage Factor for Landfilled Paper Products

(a) Material	(b) Ratio of Carbon Storage to Dry Weight (g C/Dry g)	(c) Ratio of Dry Weight to Wet Weight	(d) Ratio of Carbon Storage to Wet Weight (g C/Wet g) (d = b × c)	(e) Amount of Carbon Stored ($MTCO_2E$ per Wet Ton)
Corrugated Containers	0.26	95%	0.25	0.82
Magazines/Third-Class Mail	0.26	95%	0.25	0.82
Newspaper	0.42	95%	0.40	1.33
Office Paper	0.05	95%	0.05	0.16
Phonebooks[b]	0.42	95%	0.40	1.33
Textbooks[c]	0.05	95%	0.05	0.16

[a] Based on estimates developed by Morton Barlaz at North Carolina State University; see Barlaz (1998).
[b] Newspaper used as a proxy.
[c] Office Paper used as a proxy.

5. LIMITATIONS

Aside from the limitations associated with the forest carbon storage estimates as described in the Forest Carbon Storage chapter, the following limitations are associated with the paper products emission factors:

The emission factors associated with producing and recycling paper products are representative of manufacturing processes in the mid-1990's, and may have changed since the original life-cycle information was collected; depending upon changes in manufacturing process, such as efficiency improvements, fuel inputs and compositional changes, energy use and GHG emissions from virgin and recycled production of these products may have increased or decreased.

Composting is not included as a materials management pathway due to a lack of information on the GHG implications of composting paper products. The composting factor in WARM, described in the Composting chapter, assumes a generic compost mix, rather than looking at materials in isolation. There are no quantifiable data to measure the effect of adding paper to a compost pile. However, EPA is planning to further investigate this topic, to enable better assessments of composting emission factors for paper products.

The energy content (by weight) and landfill carbon storage for phone books and textbooks are assumed to be the same as those for newspaper and office paper, respectively, while in fact they may be different, since phone books and textbooks include covers and binding materials. EPA does not expect that this difference would have a large influence on the combustion or landfilling emission factors.

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